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ON THE MOTIONS OF THE BRIGHTER CLASS B STARS.[1]

By W. W. Campbell.

In *Annals Harvard College Observatory,* **56,** No. II, Professor Pickering first called attention to the remarkable peculiarities which exist in the distribution of the helium, or Class B, stars. He found them, in general, in or near the Milky Way. Dividing the sky into four regions of equal area whose galactic latitudes are included between + 90° and + 30°, + 30° and 0°, 0° and — 30°, and — 30° and — 90°, the numbers of Class B stars in the four regions, according to Pickering, are 22, 219, 509, and 53, respectively; or, in percentages, 3, 27, 63, and 7. These stars are even more closely related to the Milky Way than the numbers indicate.

Classifying these stars according to their visual magnitudes, Professor Pickering found that nearly all of them are comparatively bright. The tabulations indicate "that of the bright stars, one out of four belongs to this class, while of the stars of the sixth magnitude there is only one out of twenty; and that few, if any, would be found fainter than the seventh or eighth magnitude."

For guidance in preparing practicable programs for coöperative observations of stellar radial velocities, I have had all the stars brighter than visual magnitude 6.51 listed in the *Revised Harvard Photometry* classified according to spectral types and visual magnitudes. The following data, very closely approximate, are of interest in this connection:—

Magnitude.	Class B.	Class A.	Class K.
To 5.01	350	318	403
5.01–5.50	217	346	318
5.51–6.00	163	790	560
6.01–6.50	164	1,423	939[2]

These figures are of course in accord with Pickering's early statement concerning the decreasing number of Class B stars with decreasing brightness; and they further appear to indicate, at least within the range of magnitudes studied, that the numbers of Class A stars *increase*, in reference to the whole number of stars, with decreasing brightness.

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[1] Abstract from *Lick Observatory Bulletin,* No. 195.

[2] In *Revised Harvard Photometry* there are about 562 stars of all spectral types whose visual magnitudes are fainter than 6.50.

FROST and ADAMS noted[1] that the numerical mean of the radial velocities of twenty Class B stars observed by them was 7^{km} per second, after correcting for the solar motion; or, if the algebraic sign be regarded, $+ 4.6^{km}$. They thus called attention to the apparently small radial velocities of Class B stars, and at the same time to the exceedingly small proper motions of these stars, indicating "that the stars of the *Orion* type are as a class very remote."

In the winter of 1909-10, with the assistance of my colleagues, I based a determination of the elements of the motion of the solar system upon the radial velocities of 1,047 stars of all types, including thirteen nebulæ. First, an equation was written for each star, and the 1,047 equations were combined and solved in accordance with the method of least squares. The solar apex was placed at R. A. 273°.5 and Decl. + 28°.0; and the deduced velocity was 17.73^{km}. Secondly, the 1,047 individual velocities were combined into 172 groups, each group consisting of neighboring stars, and the 172 resulting equations were combined and solved in the usual manner. This second solution placed the solar apex at R. A. 272°.0 and Decl. + 27°.5, and the deduced velocity was 17.77^{km} per second.

Assuming the position of the apex as defined by the second solution, I made the velocity of the solar system the only unknown quantity, and re-determined this separately, first, for stars of classes O, B, A, and F to F4 inclusive; and, secondly, for the stars in classes F5 to F9 inclusive, G, K, and M. These divisions constitute roughly SECCHI's Type I and Type II. The velocity of the solar system determined from 330 stars of SECCHI's Type I (not including the 13 nebulæ) was 17.69^{km}, and the velocity from 704 stars of SECCHI's Type II was 18.06^{km}. Comment on these solutions is limited here to a peculiarity in the apparent velocities of the Class B stars, of which 138 were utilized. Eliminating from their observed velocities the components due to the solar motion, there resulted

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[1] *Decennial Publications*, University of Chicago, **8**, 105, 1904.

138 residuals which were apparently the radial components of their individual motions with reference to the position in space occupied at any instant by the solar system. The algebraic mean of the 138 residual velocities was $+4.93^{km}$ per second. The residuals for Class B stars in the southern hemisphere and for those of positive declination in the *Orion* region were greater in general than the residuals for the northern stars of Class B. This, we now know, was due to the small value of the velocity of the solar motion, 17.8^{km}, with which they were computed. Further, as there were twice as many Class B stars in the southern region as in the northern, the average residual was increased considerably above that which would have been furnished by a higher velocity of the solar system, say 20^{km} per second. The possible significance of the mean residual, nearly 5^{km} per second, positive, was discussed at considerable length in the Silliman lectures.

In brief, if we give a literal interpretation to the mean residual, it would signify that the universe of Class B stars is expanding, with reference to the position of the solar system as a center, at the rate of 4.93^{km} per second; but we did not attach great weight to this interpretation.

A personal equation, systematically positive, in the measurement of spectrograms would explain the phenomenon, but this explanation seems improbable. Observations of a few Class B spectra made at other observatories had been published, and the results are either in good agreement with those obtained with the Mills spectrographs on Mount Hamilton and on San Cristobal, or these published velocities are in general larger than ours.

A more probable explanation, it seems to me, is that the wave-lengths of the lines in the Class B spectra, adopted by the radial velocity observers, err in being too small. An average increase of 0.07A in the wave-lengths of all the lines utilized would fully explain the phenomenon. Unfortunately, there is no apparent means of testing this question directly; but the question of causes is an interesting one. It is recognized that high pressures in radiating or absorbing media not only broaden spectral lines but shift their apparent centers in general in the direction of greater wave-lengths. The absorption lines—or absorption bands preferably—in Class B spectra are usually of considerable breadth. It appears that axial rotations of the stars can be but minor factors in the broadening of lines. It seems not impossible that the conditions existing in Class B stars are such that the absorptions are effective at great depths in their atmospheres under high pressures, as well as in the surface strata under low pressures. If we grant the efficiency of this factor, the systematic positive tendency given to observed radial velocities of Class B stars is in a fair way to be explained.

Another hypothesis, perhaps simpler, should be mentioned. Many of the helium lines, which are the most prominent lines in Class B stars, occur in pairs in the laboratory spectrum of helium;[1] as examples, the lines at 4026A, 4120A, 4471A, and 4713A, in the region utilized by radial velocity observers. In every case the more refrangible component is stronger than the less refrangible. The laboratory line at 4471.646A has intensity six, and its companion at 4471.858A has intensity less than one; and somewhat similarly in other cases. The interval between the components of the pairs corresponds approximately to a radial velocity difference of 15^{km}. In much of the radial velocity determinations at the Yerkes Observatory, at the Lick Observatory, at Santiago, Chile, and perhaps elsewhere, the wave-length of the helium line in this region of spectrum of Class B stars has been assumed to be 4471.676A, obtained by giving weight six to the wave-length of that component whose intensity is six, and weight one to that of the component whose intensity is about one.

If conditions in Class B stars are such that the relative intensities of the red components of the helium pairs are considerably augmented, so that the effective wave-length of a pair is greater than we have assumed it to be, from laboratory measurements, it is possible we should not need to look further for the explanation of the positive discrepancy. It is known to experienced radial velocity observers that the systems of wave-lengths adopted for the lines of different elements may be satisfactory for one Class B spectrum, and apparently quite unsatisfactory for another Class B spectrum. Here may exist a fruitful field for investigation. Adopted wave-lengths for the helium lines must of course harmonize with wave-lengths adopted for the hydrogen, oxygen, silicon, and other lines existing in the same spectrum, so that all the lines in a given spectrum will yield equal radial velocities.

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[1] RUNGE and PASCHEN, *Astrophysical Journal*, **3**, 11, 1896.

There can be little doubt that the Class B stars of the *Orion* region are or have been intimately associated with the great nebulous structures which we know to exist there. The observed velocities for the densest part of the *Orion* nebula, as obtained by KEELER, VOGEL, and EBERHARD, WRIGHT, FROST, and ADAMS, are in excellent agreement, with mean value + 17.4^{km} per second.[1] The observed radial velocities of the Class B stars in the *Orion* region, though differing in essentially the usual amounts from one another, average about + 22½^{km}. Here again we have an indication, more or less weighty, that the observed radial velocities of Class B stars are for some unknown reason about five kilometers too great.

In May, 1910, KAPTEYN and FROST utilized the radial velocities of sixty-one Class B stars [2] whose radial velocities had been observed chiefly at the Yerkes Observatory, and in part at other observatories, to determine the velocity of the solar motion, assuming the apex to be at R. A. 269°.7 and Decl. + 30°.8. The sixty-one stars were grouped principally in the vicinities of the apex and antapex. Thirty-two stars near the apex gave a velocity of 18.38^{km} per second, and twenty-nine stars near the antapex 28.38^{km} per second. The difference in the two deduced velocities is (as it should be) almost exactly twice the mean residual + 4.93^{km}, which I had previously obtained from 138 Class B stars. These investigators adopted the approximate mean of the two values, 23.3^{km}, as the most probable velocity of the solar system with reference to the system of sixty-one stars employed as a basis for the solution.

This difference of 10^{km} in the velocity of the solar system afforded by the northern group and the southern group was probably the incentive to an extensive investigation which led Professor KAPTEYN to announce in a lecture in September, 1910, on Mount Wilson, that essentially all of the Class B stars in the great region of sky lying between R. A. 12^h and 18^h and Decl. 0° and —70° are traveling together through space along lines essentially parallel with velocities essentially equal; and that essentially all of the Class B stars in another great region lying between R. A. $2^h\ 50^m$ and $4^h\ 30^m$ and Decl. + 15° and + 55° were traveling together along lines nearly parallel, with velocities nearly equal; these two great clusters of stars, occupying antipodal regions of the sky, moving in such a manner that they are relatively separating with a speed of about 10^{km} per second. Although these two regions are on the average midway between the apex and antapex, we here again meet this difference of 10^{km}, or approximately twice the mean residual velocity of Class B stars, $+4.93^{km}$ per second.[1]

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[1] KEELER noted that this observed velocity must be due in great part to the motion of the solar system. If we assume the solar system to be moving toward the point R. A. 270°, Decl. + 30°, with a speed of 20 km. per second, the residual radial velocity of the *Orion* nebula becomes + 0.7 km.

[2] *Astrophysical Journal*, **32**, 83, 1910.

In December, 1910, Mr. Benjamin Boss published[2] the results of an interesting study of the proper motions of the Class B stars made by him under the direction of Professor Lewis Boss, in December, 1909; the proper motion materials having been afforded by the data of Boss's "Preliminary General Catalogue" of 6,188 stars. The two groups of Class B stars chiefly discussed by Mr. Boss lie entirely within the boundaries of the two greater groups to which Kapteyn's lecture referred. A number of other groups were treated by Mr. Boss only slightly less thoroughly; but, as in the case of minor groups pointed out in Pickering's pioneer paper, we shall not refer to them in this place. I understand Mr. Benjamin Boss's conclusions to be that while the proper motions of the two groups of stars are such as to cause the stars to move in the same general direction, but each in its separate direction, the peculiarities are largely, and perhaps wholly, the parallactic effect of the Sun's greater velocity as compared with the real velocities of the Class B stars themselves. Mr. Boss arbitrarily assumed that all stars in one of the groups occupied a common point a century ago, and he has charted the positions which the proper motions of the several stars during the century would cause them to have at the present time. It seems clear from an examination of his chart that a solar motion three times as great as that component of the real motion of each star, which is along or at right angles to the great circle passing through the star and two apices, would fully account for the observed motions. And similarly for the other cluster.

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[1] Unfortunately I must quote from memory on the main points in Professor Kapteyn's lecture, as he has apparently published neither the results nor the evidence, and I carried away no notes on the subject.

[2] *Astronomical Journal,* **26,** 163, 1910.

That there cannot be strongly marked systematic tendencies in the proper motions of the Class B stars seems evident from Professor LEWIS BOSS's determination of the apex of the solar motion from stars exclusively of this class. These stars place the apex at R. A. 274°.2, Decl. + 36°.1;[1] whereas BOSS's general solution for the solar motion, involving the stars of all spectral classes, places the apex only four degrees away, at R. A. 270°.5, Decl. + 34°.3. If there is strong systematic tendency of the proper motions in KAPTEYN's southern region (R. A. 12^h to 18^h, Decl. 0° to — 70°) the Class B apex should be far removed from the apex depending upon all classes, unless there is a systematically situated great group of Class B stars whose proper motion peculiarities are precisely the opposite of the peculiarities in the first group.

It has recently been announced by EDDINGTON[2] that there are moving clusters of stars, comprising all[3] the Class B stars, in the region R. A. 2^h to 6^h, Decl. + 36° to + 70°, one group containing ten stars and the other sixteen stars.

It is evident that the motions of the Class B stars present extremely interesting problems.

The extensive radial velocity programs observed by the Lick Observatory, University of California, on Mount Hamilton and on Cerro San Cristobal, through means afforded in good measure by the late Mr. D. O. MILLS, began in general with those stars whose spectra contain sharply defined lines, and which are, therefore, capable of accurate measurement. For several years we made little effort to include stars of classes F, A, B, and O. Our delay in observing stars of classes O, B, and A was especially marked, for these were known to constitute the chief part of Professor FROST's program of observation. The essential completion of the observing program for stars of classes G, K, and M has permitted us in recent years to secure observations of essentially all Class B and Class A stars, as bright as the fifth magnitude, in both hemispheres, whose spectra are amenable to measurement with 3-prism dispersion.

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[1] *Astronomical Journal*, **26**, 166, 1910.

[2] *Monthly Notices Royal Astronomical Society*, **71**, 43-44, 1910.

[3] Two Class B stars in this area, Boss Nos. 678 and 1204, were evidently overlooked.

The present investigation is based upon the results from 225 Class B stars. Twenty-two of these have visual magnitudes fainter than 5.0, but these cannot be said to render the materials non-homogeneous, for the additions of faint stars to the observing programs were not made, so far as I am aware, on account of any peculiarities attaching to these stars. Two hundred and three are equal to or brighter than 5.0 magnitude. The *Revised Harvard Photometry* lists 350 Class B stars (possibly one or two more or less than 350) brighter than 5.01 magnitude; 116 of these in the northern hemisphere and 234 in the southern. There are, therefore, 147 Class B stars brighter than 5.01 not represented in the table, chiefly because there are amongst them many spectroscopic binary systems as yet uninvestigated as to their orbital motions, and in part because the spectral lines in many are too ill-defined for satisfactory measurement under high dispersion.

Of the 225 stars, 77 are north and 148 are south of the equator. Inasmuch as there are twice as many of these stars in the southern hemisphere as in the northern, as they are closely clustered in and near the Milky Way, with only sporadic cases far from the Milky Way, and as their velocities are known to be affected with an apparent systematic error of 5^{km} per second, more or less, it would seem to be a useless piece of work to determine the position of the Sun's apex from them; and, further, that great care must be exercised in deducing the velocity of the solar motion from them. The least objectionable procedure appeared to be to divide the 225 stars into groups of substantially equal areas, but making certain areas larger and adjoining areas smaller in order to avoid assigning too great a number of stars to one group and too small a number to another. Accordingly, thirty-five groups of stars were formed; fifteen in the northern hemisphere, seventeen in the southern hemisphere, and three overlapping the equator. Three solutions for the velocity of the solar system from these stars have been made by my assistants and colleagues in the past month.

SOLUTION I.

It was assumed that the solar motion is toward the apex R. A. 270°.5, Decl. + 34°.3, determined by Boss's general solution from all spectral classes; and it was further assumed that each observed velocity contains an unavoidable but systematic error K. The mean right ascension, declination, and observed velocity were formed for each of the thirty-five groups, and the angular distance d of the center of each group from the assumed apex was computed. We obtained thirty-five equations of the form—

$$V_0 \cos d + K - V = O,$$

in which V_0 is the velocity of the solar system with reference to the system of Class B stars, and V is the mean of the observed radial velocities for the stars in each group. The least squares solution gave—

$$V_0 = -19.87^{\text{km}} \pm 0.82^{\text{km}}$$
$$K = +\ 3.94 \quad \pm 0.54$$

In order to determine whether the use of the term K had seriously affected the resulting value of V_0, we neglected the K term and obtained from those groups whose centers are nearer the apex and antapex than the distances given below:—

Distance from Apices.	V_0
Less than 50°	-20.0^{km}
" " 60	-20.1
" " 70	-20.7

It is clear that the introduction of the K term does not affect significantly the resulting value of the velocity of the solar system.

SOLUTION II.

Mr. Benjamin Boss combined the data for stars of classification B8 and B9 with Class A stars and not with Class B stars, because the proper motions of the late B types more nearly resemble those of Class A than those of early B types. Our charting of the 225 Class B stars concerned confirmed Mr. Boss's conclusions as to the character of the proper motions of the B8 and B9 stars, and further showed that the B8 and B9 stars on our observed list are distributed rather uniformly over the sphere. It therefore seemed desirable to base a solution for the velocity of the solar system upon the 180 stars of classification B to B5 inclusive, and to exclude the forty-five stars with classification B8 and B9.

The stars were divided into thirty-two groups, and the solution for the solar motion was made as before, assuming the apex to be at R. A. 270°.5 and Decl. + 34°.3. We obtained—

$$
\begin{aligned}
V_0 &= -20.69^{km} \pm 0.73^{km} \\
K &= +\ 4.70 \quad \pm 0.47
\end{aligned}
$$

The value of K at different distances from the apex was tested as follows:—

Using $V_0 = -20.7^{km}$, the groups at various distances from the apex and antapex gave—

Distance from Apices.	K
Less than 30°	$+3.98^{km}$
" " 50	$+4.06$
" " 60	$+4.27$
50°-130	$+5.19$
60 -120	$+5.31$
70 -110	$+4.85$

We cannot doubt the objective reality of the K term.

We tested KAPTEYN's two-drift theory in terms of these stars. The solar motion component, $-20.7^{km} \cos d$, and the constant, $K = +4.70^{km}$, were taken from the observed velocity of each star, thus obtaining the star's own radial velocity with reference to the entire system of B to B5 stars employed. If there is a preference for motion along the line joining the two vertices, the residual radial velocities should be greater for stars near the vertices than for stars midway between the vertices, assuming the stars in the different regions to have the same average speeds in space. The mean velocities are tabulated as below, in terms of the distances of the stars from the assumed vertex at R. A. 93°, Decl. + 12°.

TABULATION OF RESIDUAL VELOCITIES WITH REFERENCE TO DISTANCE FROM VERTEX AT R. A. 93°, DECL. + 12°.

24	Class B-B5 stars, zone 0°- 30°,	average speed, + and —,	5.30^{km}
10	Class B-B5 stars, zone 150°-180°,	average speed, + and —,	7.99^{km}
34	Class B-B5 stars, in both zones,	average speed, + and —,	6.09^{km}

30	Class B-B5 stars, zone 30°- 60°, average speed, + and —,	5.93^{km}
33	Class B-B5 stars, zone 120°-150°, average speed, + and —,	7.42^{km}
63	Class B-B5 stars, in both zones, average speed, + and —,	6.71^{km}
80	Class B-B5 stars, zone 60°-120°, average speed, + and —,	5.87^{km}
92	Class B-B5 stars, in all zones, average speed, receding,	$+5.68^{km}$
85	Class B-B5 stars, in all zones, average speed, approaching,	-6.79^{km}
177	Class B-B5 stars, in all zones, average speed, + and —,	6.21^{km}

The individual velocities appear not to be a maximum in the zones immediately surrounding this vertex and the antipodal vertex. (The inclusion of the forty-five residual velocities of the Class B8-B9 stars, computed from the solar motion elements of Solution II, would not change the results sensibly.) Therefore this evidence is not in support of preferential motions of the Class B stars with reference to the assumed vertices.

The average radial velocity of the 177·brighter B to B5 stars is 6.21^{km} per second.

It is of interest to study the residual velocities in the area R. A. 12^h to 18^h, Decl. 0° to —70°, as below, including also the five B8 and B9 observed in this region.

Tabulation of Residual Velocities in the Region R. A.

12^h to 18^h, Decl. 0° to —70°.

30	Class B-B5 stars, positive, average	$+6.18^{km}$
20	Class B-B5 stars, negative, average	-7.63^{km}
50	Class B-B5 stars, + and —, average	6.76^{km}
50	Class B-B5 stars, algebraic, average	$+0.65^{km}$
32	Class B-B9 stars, positive, average	$+6.07^{km}$
23	Class B-B9 stars, negative, average	-7.83^{km}
55	Class B-B9 stars, + and —, average	6.81^{km}
55	Class B-B9 stars, algebraic, average	$+0.26^{km}$

It thus appears that the numerical average velocity is slightly larger for the 55 stars in this region than for all the 177 B type stars utilized; and an examination of the individual residual velocities will show as great a variety of radial velocities in this octant of the sky as elsewhere. The algebraic mean of the fifty-five velocities is $+0.26^{km}$; that is, the system of fifty-five stars as a whole is neither receding from nor approaching the point occupied at any moment by the solar system.

In the region R. A. $2^h\ 50^m$ to $4^h\ 30^m$, Decl. + 15° to 55°, we have only 12 observed stars, six[1] of which are in the *Pleiades* group. There are—.

6	Class B-B9 stars, positive, average	$+4.27^{km}$
6	Class B-B9 stars, negative, average	-5.78^{km}
12	Class B-B9 stars, + and —, average	5.02^{km}
12	Class B-B9 stars, algebraic, average	-0.76^{km} .

Omitting the six *Pleiades* stars—

6	Class B-B9 stars, + and —, average	5.7^{km}
6	Class B-B9 stars, algebraic, average	-0.5^{km}

These data, depending upon only six stars, are too meager to have much statistical weight, but they lend no support to the hypothesis of approximately equal and parallel motion.

The two Class B9 stars, Nos. 1035 and 1040, just outside of this region, do seem to possess parallel and equal motions, as shown by the proper motion and radial velocity results.

SOLUTION III.

At this point a solution for the direction and speed of the solar motion based upon about 1,200 observed radial velocities of stars of all spectral types was carried through, with the following results:—

R. A. of apex = 268° 32′
Decl. of apex = + 25 07
$V_0 = -19.52^{km}$
$K = +1.91^{km}$

Neglecting K, another solution from the 1,200 velocities gave—

R. A. of apex = 268° 30′
Decl. of apex = + 25 20
$V_0 = -19.54^{km}$

As all the recent spectrographic solutions for position of the apex place it from seven to nine degrees south of the position assigned by Boss's proper motion solution, it seemed desirable in studying the motions of the *brighter* stars to assume the position of the apex at a point midway[1] between the spectrographic and the proper motion apices. This point falls conveniently at R. A. 270°, Decl. + 30°.

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[1] Observed at the Yerkes Observatory.

The third solution for the velocity of the solar system, based upon all of the 225 stars, including the forty-five of types B8 and B9, and upon the assumed apex at R. A. 270°, Decl. + 30°, was now made. The B8 and B9 stars were included because a discussion of their residual velocities based upon Solution II revealed only a small difference of their average speed from that of the B to B5 stars. The 225 stars were divided into thirty-five groups, fifteen in the northern hemisphere, seventeen in the southern hemisphere, and three overlapping the equator. Solution III, by the method of least squares, afforded the following results:—

$$\begin{aligned} V_0 &= -20.19^{\mathrm{km}} \pm 0.81^{\mathrm{km}} \\ K &= +4.07^{\mathrm{km}} \pm 0.53^{\mathrm{km}} \end{aligned}$$

The residual velocities for the individual stars were found as usual by removing the solar motion component and the constant *K*. These velocities were tabulated with reference to the angular distances from the apex, as follows:—

TABULATION OF RESIDUAL VELOCITIES WITH REFERENCE TO ANGULAR DISTANCES FROM APEX AT R. A. 270°, DECL. + 30°.

Zones 0°-30°, 150°-180° from apex.

25	Class B-B5 stars, positive, average	$+6.92^{\mathrm{km}}$
17	Class B-B5 stars, negative, average	-5.32^{km}
42	Class B-B5 stars, + and —, average	6.27^{km}
9	Class B8-B9 stars, + and —, average	4.57^{km}
51	Class B-B9 stars, + and —, average	5.97^{km}

Zones 30°-60°, 120°-150° from apex.

29	Class B-B5 stars, positive, average	$+5.89^{\mathrm{km}}$
31	Class B-B5 stars, negative, average	-6.30^{km}
60	Class B-B5 stars, + and —, average	6.10^{km}
13	Class B8-B9 stars, + and —, average	7.14^{km}
73	Class B-B9 stars, + and —, average	6.29^{km}

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[1] It must be remembered that the spectroscopic results thus far apply to stars on the average more than a magnitude brighter than those used in proper motion solutions; and the discordance may eventually find explanation in this fact.

Zones 60°-90°, 90°-120° from apex.

50	Class B-B5 stars, positive, average	$+6.43^{\mathrm{km}}$
28	Class B-B5 stars, negative, average	-7.65^{km}
78	Class B-B5 stars, + and —, average	6.87^{km}
23	Class B8-B9 stars, + and —, average	7.24^{km}
101	Class B-B9 stars, + and —, average	$\mathbf{6.96}^{\mathrm{km}}$

Totals for the six zones.

104	Class B-B5 stars, positive, average	$+6.40^{\mathrm{km}}$
76	Class B-B5 stars, negative, average	-6.58^{km}
180	Class B-B5 stars, + and —, average	6.47^{km}
45	Class B8-B9 stars, + and —, average	6.68^{km}
225	Class B-B9 stars, + and —, average	$\mathbf{6.52}^{\mathrm{km}}$

There is an excellent "balance" preserved in the residual in all zones; but the mean velocities near the apices appear to be a little smaller than midway between them.

The residual velocities afforded by Solution III were next tabulated with relation to the distances of the stars from the assumed preferential vertex at R. A. 93°, Decl. + 12°, as below.

TABULATION OF RESIDUAL VELOCITIES WITH REFERENCE TO ANGULAR DISTANCES FROM VERTEX AT R. A. 93°, DECL. + 12°.

Zones 0°-30°, 150°-180° from vertex.

26	Class B-B5 stars, positive, average	$+6.78^{\mathrm{km}}$
11	Class B-B5 stars, negative, average	-4.84^{km}
37	Class B-B5 stars, + and —, average	6.20^{km}
8	Class B8-B9 stars, + and —, average	5.02^{km}
45	Class B-B9 stars, + and —, average	$\mathbf{5.99}^{\mathrm{km}}$

Zones 30°-60°, 120°-150° from vertex.

35	Class B-B5 stars, positive, average	$+6.49^{\mathrm{km}}$
30	Class B-B5 stars, negative, average	-7.12^{km}
65	Class B-B5 stars, + and —, average	6.78^{km}
17	Class B8-B9 stars, + and —, average	5.06^{km}
82	Class B-B9 stars, + and —, average	$\mathbf{6.42}^{\mathrm{km}}$

Zones 60°-90°, 90°-120° from vertex.

43	Class B-B5 stars, positive, average	$+6.10^{\mathrm{km}}$
35	Class B-B5 stars, + and —, average	6.35^{km}
78	Class B-B5 stars, + and —, average	6.35^{km}
20	Class B8-B9 stars, + and —, average	8.76^{km}
98	Class B-B9 stars, + and —, average	$\mathbf{6.84}^{\mathrm{km}}$

Totals for the six zones.

104	Class B-B5 stars, positive, average	$+6.40^{km}$
76	Class B-B5 stars, negative, average	-6.58^{km}
180	Class B-B5 stars, + and —, average	6.47^{km}
45	Class B8-B9 stars, + and —, average	6.68^{km}
225	Class B-B9 stars, + and —, average	6.52^{km}

The average radial velocities of the stars in the zones 30° wide are seen to be in remarkably close accord; those nearest to the vertices in fact affording the smallest results. If we include in this tabulation the forty-five stars of classes B8 and B9, the residual velocities for all the Class B stars appear to increase slightly in passing from the zones which immediately surround the two antipodal vertices to the zones midway between the vertices.

It is thus clear that the Class B stars upon which the present investigation is based lend no support to the hypothesis of preferential motions toward and from the assumed vertices.

In the region R. A. 12^h to 18^h, Decl. 0° to — 70°:—

38	Class B-B9 stars, positive, average	$+6.86^{km}$
17	Class B-B9 stars, negative, average	-8.45^{km}
55	Class B-B9 stars, + and —, average	7.35^{km}
55	Class B-B9 stars, algebraic, average	$+2.11^{km}$

The numerical mean 7.35 of the fifty-five residual velocities in this octant of the sky is in good agreement with the numerical average for the same stars, 6.81^{km}, afforded by Solution II; and the average for this octant from both solutions is nearly one kilometer greater than the average for the B types for the entire sky; that is, *the average range of radial velocities for this region is greater than for the rest of the sky.*

In the region R. A. $2^h\ 50^m$ to $4^h\ 30^m$, Decl. + 15° to + 55°, excluding six belonging to the *Pleiades* cluster—

3	stars, positive, average	$+6.5^{km}$
3	stars, negative, average	-4.8^{km}
6	stars, + and —, average	5.6^{km}
6	stars, algebraic, average	$+0.8^{km}$

These stars are of course too few in number to have any statistical weight; but they do not give any evidence of a drift.

In several respects Solution II, which excluded classes B8 and B9, is apparently more satisfactory than Solution III, in that the residual velocities afforded by the former are in appreciably better balance over the sky than those from Solution III. The average velocity of stars of Class B to B5 inclusive, 6.21^{km}, afforded by Solution II, is increased to 6.47^{km} in Solution III.

To make possible a comparison of the proper motions, μ, with the radial velocities, the proper motions as given in Boss's *"Preliminary General Catalogue"* were resolved into two components; one of these, v, lying along the great circle passing through the star and the apex, and the other, τ, at right angles to this.

The τ components of proper motions, as is well known, are not influenced by the solar motion; and, theoretically at least, they afford a simple method for determining the approximate average distance of a homogeneous class of stars whose radial velocities have been determined by the spectrograph. If a great number of stars assumed to be moving at random have been observed radially and the necessary corrections have been applied for the solar motion components, the average residual radial velocity, irrespective of sign, should correspond to the average of the τ components for the same stars. The relationship existing between the average radial velocity component and the proper motion components is a complicated one when the stars are at appreciably different distances from the observer, but the relationship can be deduced, provided the law of distance-distribution is known.

Assuming that the 180 stars of Class B to B5 are at essentially the same distance from the observer, and that the forty-five stars of Class B8 and B9 are likewise at essentially uniform distance from the observer, we may express the distance of each group in light years by the equation—

$$D_m \text{ (in light years)} = 0.6875 \frac{V_m}{\tau''_m}$$

in V_m is the mean radial velocity of the stars in the group without regard to the sign, and τ''_m is the mean of the τ components, without regard to sign, expressed in seconds of arc. We may similarly express the distance in terms of the mean parallax of the group as follows:—

$$\pi_m = 4.738 \frac{\tau''_m}{V_m}$$

The τ values are combined below; first, for the 225 stars in the entire sky, and, second, for the fifty-five stars in the octant R. A. 12^h to 18^h, Decl. 0° to —70°.

ALL τ VALUES.

84½[1]	Class B-B5 stars, $\Sigma\tau = +0''.676$, mean	$\tau = +''.0081$
95½	Class B-B5 stars, $\Sigma\tau = +0''.702$, mean	$\tau = -''.0072$
180	Class B-B5 stars, + and —, mean	$\tau = ''.0076$
180	Class B-B5 stars, algebraic, mean	$\tau = -''.0001$
25	Class B8-B9 stars, $\Sigma\tau = +0''.487$, mean	$\tau = +''.0195$
20	Class B8-B9 stars, $\Sigma\tau = -0''.367$, mean	$\tau = -''.0184$
45	Class B8-B9 stars, + and —, mean	$\tau = ''.0190$
45	Class B8-B9 stars, algebraic, mean	$\tau = +''.0027$
225	Class B-B9 stars, + and —, mean	$\tau = ''.0099$
225	Class B-B9 stars, algebraic, mean	$\tau = +''.0006$

τ VALUES IN THE REGION R. A. 12^h TO 18^h, DECL. 0° TO —70°.

18½[1]	Class B-B5 stars, $\Sigma\tau = +0''.169$, mean	$\tau = +''.0091$
31½	Class B-B5 stars, $\Sigma\tau = -0''.217$, mean	$\tau = -''.0067$
50	Class B-B5 stars, + and —, mean	$\tau = ''.0076$
50	Class B-B5 stars, algebraic, mean	$\tau = -''.0010$
2	Class B8-B9 stars, $\Sigma\tau = +0''.091$, mean	$\tau = +''.0455$
3	Class B8-B9 stars, $\Sigma\tau = -0''.023$, mean	½ $= -''.0077$
55	Class B-B9 stars, + and —, mean	$\tau = ''.0095$
55	Class B-B9 stars, algebraic, mean	$\tau = +''.0004$

It will be noticed that the average value of τ for the B-B5 stars in region R. A. 12^h to 18^h is identical with its average value for all parts of the sky; and that the average τ for the B8-B9 stars in the region R. A. 12^h to 18^h is almost identical with the average τ for the B8-B9 stars in all parts of the sky. That the apparent motion of these fifty-five stars as a group is almost exactly toward the antapex is shown by the small value of the algebraic mean τ.

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[1] One zero value of τ was assigned in half weight to the positives and to the negatives.

It is probable, and essentially certain, that the mean radial velocities of the stars determined from Solutions II and III are too great, for at least two reasons, of which we here mention but one. Several of the stars utilized have unfortunately been observed radially but once, and several additional stars but twice. It is probable that one in two or three of these will later be found to be spectroscopic binary systems; at least, a large proportion of those stars whose radial velocities have been incompletely observed will almost surely reveal a binary character. Inasmuch as the systematic velocities of Class B binary stars are small and the orbital velocities are great, it must happen that a considerable number of casual radial velocity results for such stars will be greater in magnitude than the systematic velocities of the same binary stars.

Assuming for this reason that the mean residual velocity of Class B to B5 stars is 6^{km} per second (reduced from 6.21^{km}, Solution II, and 6.47^{km}, Solution III), and that the average τ component is $0''.0076$, the average distance of the 180 Class B stars becomes—

$$D_{\mathrm{m}} = 543 \text{ light years}$$
$$\pi_{\mathrm{m}} = 0''.0060$$

The corresponding quantities for the forty-five stars of Class B8 and B9, assuming the mean radial velocities to be 6.7^{km} and the mean value of τ to be $0''.0190$, are—

$$D_{\mathrm{m}} = 242 \text{ light years}$$
$$\pi_{\mathrm{m}} = 0''.0134$$

The true values of D_{m} may be 50 per cent or more greater than these.

The v component of a proper motion is a compound of the star's own motion, and of the component due to the solar motion. If the stars are moving at random and in effect uniformly distributed in position and distance, the component v_1 due to the solar motion may be eliminated more or less successfully through the medium of the τ components, and the residuals, $v - v_1$, should sum up approximately to zero in each extensive area of the sky.

Assuming the velocity of the solar system with reference to the Class B stars to be 20.2^{km}, the average radial velocity of the

Class B to B5 stars as 6^{km} and the distance of these stars as just computed, the solar motion component, v_1, was determined for each star as if it were situated at the average distance of the observed Class B stars, and as a further function of its angular distances from the apex, and subtracted from the observed value of v.

The prevailing negative values of $v - v_1$ for the 180 Class B-B5 stars in general, and for the 50 Class B-B5 stars in the region between R. A. 12^h and 18^h, show that the parallactic corrections, v_1, as computed on the basis of $D_m = 543$ light years, are too small; whereas the v_1 corrections for the Class B8-B9 stars as computed on the basis of $D_m = 242$ light years are too large. To make $\Sigma(v - v_1) = 0$ for the Class B-B5 stars, would require that we use average distance $D_m = 430$ light years for these stars; and $D_m = 220$ light years for the 45 Class B8-B9 stars. These values must be regarded only as indications of relative distances, and not as accurate values.

There arises the question whether the mean value, 6^{km}, of the observed radial velocities utilized in determining the distances of the stars through the medium of the τ components is greater than the true value. Foregoing discussions have shown that the radial velocities of these stars in all parts of the sky occupied by them have been assigned 4^{km} more or less too great. Is this obscure source of error of such a nature that it also increases the apparent numerical mean velocity after the *average* value of the error, K, has been removed? This seems not improbable; in fact, if the systematic positive enlargement of velocities is variable, depending upon the mass or other stellar factor, an increase of mean numerical observed velocity will result. To illustrate by this extreme case: Suppose that all of the stars were really neither approaching nor receding from the solar system: their mean velocity would be zero. Assume now that a variable error, such as that described. with average value $K = +4^{km}$, and extreme limits, 0^{km} and $+8^{km}$, were involved fortuitously in the observed velocities of these stars as a function of their masses or other factor: the resulting elements for the motion of the solar system would not be changed, and the average value of the error, $K = +4^{km}$, would be eliminated, but the numerical averages of the residual velocities would have been increased from 0^{km} up to possibly 2^{km}.

At first sight it would seem that the real motions of the Class B stars are somewhat greater in the υ components than in the τ components. If real, this would be a highly interesting matter. As the apex and antapex are not far from the Milky Way, and as the Class B stars are in or closely associated with the Milky Way, we should have these stars in effect traveling more rapidly in the plane of the Milky Way than at right angles to that plane. This would be a not unreasonable expectation; for, since the gravitational matter of the stellar system (at least the luminous matter) exists in major proportions in and near the plane of the Milky Way, any acceleration in the speeds of the Class B stars due to the gravitational power of the universe would probably be larger in the plane of the Milky Way than at right angles to that plane. The radial velocity components of the Class B stars in general make comparatively small angles with the plane of the Milky Way, and they would likewise be expected to occur in greater magnitude than the linear velocities at right angles to that plane.

On certain apparently reasonable assumptions as to the distribution of the Class B stars in distance, the observed τ and υ components of proper motion and the observed radial components seem to be harmonized better by the existence of smaller linear velocities in the τ direction than in the υ and radial directions; but because we do not know the law of distance-distribution for the Class B stars, the number of these stars thus far observed radially being too small to serve as a satisfactory basis, the reality of the assumptions cannot be here asserted.

However, the observed radial velocities, considered apart from the proper-motion data, afford interesting and perhaps weighty evidence, as follows:—

One hundred and ninety-one Class B-B9 stars whose galactic latitudes are less than 30° have average residual radial velocity of 7.1^{km}.

Twenty-seven Class B-B9 stars whose galactic latitudes are between 30° and 60° have average residual velocity of 5.6^{km}.

Seven Class B-B9 stars whose galactic latitudes are between 60° and 90° have residual radial velocity of 5.4^{km}.

The evidence, necessarily based upon very few stars in high galactic latitudes, is fairly strong to the effect that the radial velocities in and close to the Milky Way are greater than the radial velocities of the stars in intermediate and high galactic latitudes.

The Class A stars furnish corroborative evidence apparently of the highest importance.

Ninety-eight Class A stars whose galactic latitudes are less than 30° have average residual radial velocity of 13.0^{km}.

Sixty-one Class A stars whose galactic latitudes are between 30° and 60° have average residual velocity of 9.2^{km}.

Eighteen Class A stars whose galactic latitudes are greater than 60° have average residual radial velocities of 5.6^{km}.

Though the Class A stars have a preference for low galactic latitudes, yet they are much more uniformly distributed over the sky than are the Class B stars; and the evidence afforded by these stars for preferential high radial velocities in low galactic latitudes can scarcely be questioned.

The evidence afforded on the same question by stars of Classes F, G, K, and M will be presented at once in another paper.

CONCLUSIONS.

I. An error, of obscure source, causes the radial velocities of Class B stars to be observed too great by a quantity, *K*, amounting to several kilometers. For stars of Class B-B5, the value of this error is approximately $K = + 4.7^{km}$ per second. The value obtained for Class B-B9 stars is $+ 4.1^{km}$. It is therefore probable that *K* is less than $+ 4^{km}$ for stars of Class B8-B9.

II. The velocity of the solar system with reference to all Class B stars observed radially on the assumption that the apex is at R. A. 270°, Decl. + 30°, is approximately $V_0 = - 20.2^{km}$. (Recent and current investigations, based upon all spectral types, indicate that the velocity of the solar system, with reference to the system of stars brighter than the fifth visual magnitude, including a few between the fifth and sixth magnitudes, is approximately 19^{km} per second.)

III. The average radial velocity of Class B-B5 stars, deduced as 6.21^{km} and 6.47^{km} in Solutions II and III, may be assumed as 6^{km} for the present. The decimals are neglected chiefly because of the influence of undiscovered spectroscopic binary systems amongst the stars used as a basis for the solutions.

IV. The observed average radial velocity of the Class B8-B9 stars, only forty-five in number, is 6.7^{km} per second. This is probably a little too large, for the same reason.

V. The radial velocities of the Class B stars appear to be essentially independent of their angular distances from the apex.

VI. The radial velocities of the Class B stars appear to be essentially independent of their angular distances from the assumed vertices of preferential motion at R. A. 93°, Decl. + 12°, and the antipodal point.

VII. The range of observed radial velocities for Class B stars in the region R. A. 12^h to 18^h, Decl. 0° to —70°, is slightly greater than for the Class B stars in the remainder of the sky, so that this evidence, as far as it goes, is opposed to the hypothesis that essentially all the Class B stars in that region are traveling along lines essentially parallel, with speeds essentially equal.

VIII. The mean value of the τ components of proper motion for the 180 Class B-B5 stars is 0″.0076; and likewise the mean value of the τ component for the fifty Class B-B5 stars in the region R. A. 12^h to 18^h, south declination, is 0″.0076.

IX. The algebraic mean of the τ components is extremely small, assuring that the position of the apex was satisfactorily assumed, considering the small number of stars involved.

X. The mean of the τ components for the forty-five stars of Class B8-B9 is 0″.0190, and the algebraic mean of the τ components is satisfactory, considering the small number of stars involved.

XI. Upon reasonable assumptions as to the space distribution of the Class B-B9 stars there appears to be evidence from the proper motion data that their components of motion in or parallel to the plane of the Milky Way are somewhat greater than the components at right angles to the plane of the Milky Way. However, these conclusions are sensitive to changes in the assumed space distribution. The clustering of these stars in and near the plane of the Milky Way and the small number of available stars imposed limitations upon the weight of the results.

XII. Considerable weight must be assigned to the observed results that the residual radial velocities for Class B-B9 stars in and near the Milky Way are greater than for those in intermediate and high galactic latitudes. The corresponding results for the observed Class A stars, which are distributed more uniformly in galactic latitudes than the Class B stars, are of great weight to the effect that the residual radial velocities are an inverse function of the galactic latitude.

XIII. As the Class B stars are now in general in or near the Milky Way, and as they are believed to represent an early stage of sidereal development, we can scarcely doubt that these stars have assumed their stellar forms in positions closely related to the Milky Way. If their motions have been accelerated by the gravitational attractions of the stellar universe, we should probably have to expect that these motions would show a more or less strong preference for the plane of the Milky Way. The Class A stars, which are believed to follow the Class B stars in effective age, seem to afford evidence strongly in harmony with this hypothesis.

XIV. Concerning KAPTEYN'S hypothesis of equal and parallel motion for essentially all the helium stars in the region R. A. 12^h to 18^h, Decl. 0° to —70°, the facts appear to be as follows:—

(*a*) The stars in this group are on the average about 90° from the solar apices, and they therefore exhibit the maximum parallactic displacements.

(*b*) The τ components for these stars are on the average exactly equal to the τ components for the observed Class B stars in the rest of the sky; and the algebraic mean of these components is essentially zero, indicating that the assumed apices represent them.

(*c*) The fainter Class B-B5 stars in this region, just as for the entire circuit of the Milky Way, have larger average τ components of proper motion than the brighter Class B-B5 stars have.

(*d*) The range of radial velocities for these stars appears to be greater than for the Class B stars in other regions of the sky, and the υ and τ linear speeds appear to be smaller than for the other Class B stars.

(*e*) The helium stars in this region appear to be neither increasing nor decreasing their distances from the point momentarily occupied by the solar system; the recession of 5^{km} per second, assigned by KAPTEYN, finding its complete explanation in the obscure error K referred to above.

(*f*) This group of stars is an interesting one, but the observed facts seem to be not out of harmony with essential fixity of position of the group both in the line of sight and across the line of sight, with radial velocities of more than average magnitude and discordance, with τ and υ linear speeds less than average, and with average parallax a little greater than for all the Class B stars.

The evidence contained in this paper is too meager to have weight concerning KAPTEYN'S hypothesis of similar drift of essentially all helium stars in the *Perseus* region, except to explain and remove the recessional speed of 5^{km} assigned to the group; but the few radial velocities observed yield essentially average discordances. EDDINGTON'S division of the major part of the northern helium group into two apparently unrelated groups would also seem to negative the hypothesis.

The unavoidable uncertainties in the observed radial velocities and in the observed proper motions afford considerable latitude for the selection of stars from the above list of 225 which appear to, or may, be moving along parallel lines with equal velocities. I could here specify several such minor groups, but the publication of definite deductions concerning these possible and probable groups is delayed for a time.

In conclusion I call special attention to the practical certainty that definitive discussion of the wave-lengths to be adopted for the lines in the several subdivisions of the Class B spectra must effect some changes in the velocities here assigned to the 225 individual stars.

In securing the observational data and the computational results contained in this paper, it affords me unusual pleasure to acknowledge assistance received from the late Mr. D. O. MILLS, from the Carnegie Institution of Washington, and from all of my colleagues in the Lick Observatory.

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